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DESCRIPTION

Method of Producing Phase Mask for Processing Optical

Fiber and Optical Fiber with Bragg Diffraction Grating

5 Fabricated by Using the Optical Fiber-Processing Phase

Mask

Technical Field

The present invention relates to a method of

10 producing a phase mask for processing an optical fiber and

also relates to an optical fiber with a Bragg diffraction

grating fabricated by using the optical fiber-processing

phase mask. More particularly, the present invention

relates to a method of producing a phase mask for

15 fabricating a diffraction grating by using an ultraviolet

laser beam in an optical fiber used for optical

communications or the like. The present invention also

relates to an optical fiber with a Bragg diffraction

grating fabricated by using the mask.

20

Background Art

Optical fibers have brought about a great revolution

in global communications and allowed high-quality and

large-capacity transoceanic telecommunications. It has

25 heretofore been known that a Bragg diffraction grating is

fabricated in an optical fiber by producing a periodic

index profile in the core along the optical fiber, and the

level of reflectivity of the diffraction grating and the

width of the wavelength characteristics of the diffraction grating are determined by the period and length of the diffraction grating and the magnitude of refractive index modulation thereof, thereby allowing the diffraction

5 grating to be used as a wavelength-division multiplexer for optical communications, a narrow-band high-reflecting mirror for use in a laser or a sensor, a wavelength selection filter for removing extra laser wavelengths in a fiber amplifier, etc.

10 However, the wavelength at which silica optical fibers exhibit a minimum attenuation and which is suitable for long-haul communication systems is 1.55 μm. Therefore, it is necessary in order to use an optical fiber diffraction grating at this wavelength that the grating

15 spacing should be about 500 nm. At the beginning, it was deemed to be difficult to make such a fine structure in the core. To make a Bragg diffraction grating in the core of an optical fiber, the conventional practice is to carry out many complicated process steps including side

20 polishing, photoresist process, holography exposure, reactive ion beam etching, etc. For this reason, the conventional practice suffers a long production time and a low yield.

However, there has recently been known a method of

25 making a diffraction grating by irradiating an optical fiber with ultraviolet radiation to produce a refractive index change directly in the core of the optical fiber. The method using irradiation with ultraviolet radiation

needs no complicated process. Therefore, increasing use has been made of the method using ultraviolet radiation with the progress of peripheral techniques.

With the method using ultraviolet radiation, because the grating spacing is as fine as about 500 nm, as has been stated above, the following methods are adopted: an interference method wherein two light beams are caused to interfere with each other; a method wherein writing is carried out for each point (single pulses from an excimer laser are focused to form diffraction grating surfaces one by one); a method wherein irradiation is effected by using a phase mask having a grating; and so forth.

The above-described interference method in which two light beams are caused to interfere with each other involves problems in terms of the quality of lateral beams, i.e. spatial coherence. The method wherein writing is carried out for each point needs precise step control of the order of submicrons and requires writing many surfaces with light narrowed down. Therefore, the method suffers from a problem in terms of operability.

Accordingly, the irradiation method using a phase mask has attracted attention as a method capable of coping with the above-described problems. This method uses, as shown in Fig. 5(a), a phase shift mask 21 having grooves with a predetermined depth that are provided on one surface of a quartz substrate at a predetermined pitch. A KrF excimer laser beam (wavelength: 190 to 300 nm) 23 is applied to the mask 21 to produce a refractive index

change directly in a core 22A of an optical fiber 22,
thereby fabricating a grating (reference numeral 22B
denotes a cladding of the optical fiber 22). It should be
noted that in Fig. 5(a) an interference fringe pattern 24

5 in the core 22A is shown as enlarged so as to be readily
understandable. Fig. 5(b) is a sectional view of the phase
shift mask 21. Fig. 5(c) is a fragmentary top view
corresponding to the sectional view. The phase shift mask
21 has a binary phase type diffraction grating structure

10 in which grooves 26 with a depth D are provided on one
surface of the phase shift mask 21 at a repeating pitch P,
and a strip 27 with approximately the same width as that
of each groove 26 is provided between each pair of
adjacent grooves 26.

15   The depth D of the grooves 26 in the phase shift
mask 21 (i.e. the height difference between the strips 27
and the grooves 26) is selected so that the phase of the
excimer laser beam 23, which is exposure light, is
modulated by a π radian. Zeroth-order light (beam) 25A is

20 reduced to 5% or less by the phase shift mask 21.
Principal light (beam) emerging from the mask 21 is
separated into plus 1st-order diffracted light 25B, which
includes 35% or more of the diffracted light, and minus
1st-order diffracted light 25C. Thus, the optical fiber 22

25 is irradiated with interference fringes of predetermined
pitch determined by the plus 1st-order diffracted light
25B and the minus 1st-order diffracted light 25C, thereby
producing a refractive index change at this pitch in the

optical fiber 22.

The grating fabricated in the optical fiber by using
the above-described phase mask 21 has a uniform pitch.
Therefore, the grooves 26 of the phase mask 21 used to
5   fabricate the grating also have a uniform pitch.

To make such a phase mask, a quartz substrate coated
with an electron beam resist is irradiated with an
electron beam at regions corresponding to the grooves 26
by an electron beam writing system, and the irradiated
10   regions are removed by etching.

Incidentally, there has recently been a demand for a
chirped grating as a Bragg diffraction grating to be
formed in optical fibers. The chirped grating is such a
diffraction grating that the grating pitch increases or
15   decreases linearly or nonlinearly according to the
position in a direction (repeating direction of the
grating) perpendicular to the grating grooves. Such a
grating is used, for example, as a means for compensating
for chromatic dispersion of a high-reflecting mirror
20   having a widened reflection band or that of an optical
fiber.

To make a grating in which the grating pitch changes
linearly or nonlinearly according to the position in the
longitudinal direction of the optical fiber, as stated
25   above, on the basis of the interference of plus 1st-order
diffracted light and minus 1st-order diffracted light by
using a phase mask, it is necessary that the pitch of the
grooves of the phase mask should increase or decrease

linearly or nonlinearly according to the position as well, as will be clear from the principle shown in Fig. 5(a) (as the pitch of the grooves of the phase mask decreases, the angle formed between the plus 1st-order diffracted light and the minus 1st-order diffracted light increases, and the pitch of the interference fringes decreases). To make such a phase mask by writing using an electron beam writing system, the conventional practice needs a large amount of writing data for writing grooves or strips between them over the whole area of the mask. Accordingly, there are cases where it is difficult to produce the phase mask. The writing data may have errors occurring in relation to the address grid.

In fabricating a grating in which the grating pitch changes linearly or nonlinearly, the problem of pitch deviation (connection error) may arise at the joint between patterns different in grating pitch from each other. An optical fiber diffraction grating fabricated by using a phase mask containing such connection errors produces a large number of unwanted peaks other than the desired peak of the spectrum, as shown in Fig. 16, by way of example, which illustrates reflection characteristics. In a chirped grating, the connection errors result in ripples in the group delay characteristics. This may give rise to a serious problem when the chirped grating is used to compensate for dispersion of the optical fiber.

Disclosure of the Invention

The present invention was made in view of the above-described problems with the prior art. An object of the present invention is to provide a method of producing an

5 optical fiber-processing phase mask having minimized connection errors that may degrade the spectral line shape and group delay characteristics of an optical fiber diffraction grating fabricated by using the phase mask. The present invention also includes an optical fiber with

10 a Bragg diffraction grating fabricated by using such an optical fiber-processing phase mask.

To attain the above-described object, the present invention provides a method of producing an optical fiber-processing phase mask having a repeating pattern of

15 grating-shaped grooves and strips provided on one surface of a transparent substrate, so that diffracted light produced by the repeating pattern is applied to an optical fiber to fabricate a diffraction grating in the optical fiber by interference fringes of diffracted light of

20 different orders. In making a mask having a plurality of juxtaposed patterns having a linearly or nonlinearly increasing or decreasing pitch and a uniform groove-strip width ratio, multiple exposure is carried out to minimize difference between the pitch at the joint between patterns

25 having different pitch data and the pitch in each individual pattern.

In this case, when the plurality of patterns having different pitch data are written in juxtaposition with

each other by multiple exposure, multiple writing
operations may be carried out in the same direction.
Alternatively, the multiple writing operations may be
carried out in opposite directions.

5   The pitch of the repeating pattern of grating-shaped
grooves and strips is set so as to vary usually between
0.85 µm and 1.25 µm in order to reflect light in the near
infrared region.

       It is desirable that the difference in height
10 between the grooves and strips of the repeating pattern of
grating-shaped grooves and strips should be of such a
magnitude that a phase shift of approximately π occurs
when ultraviolet radiation for processing the optical
fiber passes through the phase mask.

15   The arrangement may be such that the repeating
pattern of grating-shaped grooves and strips is based on
writing data concerning a basic pattern consisting of one
groove and one strip, and the patterns of grooves and
strips having different pitches are continuously written
20 by using the writing data concerning the basic pattern
while varying the reduced scale for the writing data.

       In this case, it is desirable that a change in pitch
according to position of the repeating pattern of grating-
shaped grooves and strips should be determined according
25 to a change in pitch of the diffraction grating to be
fabricated in the optical fiber and should be given by a
change according to the reduced scale for the writing data
concerning the basic pattern.

It should be noted that writing may be performed by
an electron beam writing system or a laser beam writing
system.

The present invention also includes an optical fiber
5   with a Bragg diffraction grating fabricated by using an
optical fiber-processing phase mask produced by any one of
the above-described production methods.

The optical fiber with a Bragg diffraction grating
is used to compensate for dispersion of the optical fiber,
10 for example. The group delay ripple of the optical fiber
with a Bragg diffraction grating is within ±10 ps.

In the present invention, multiple exposure is
carried out to make a mask having a plurality of
juxtaposed patterns with a uniform groove-strip width
15 ratio. Therefore, positional inaccuracies are averaged as
shown in Fig. 1, so that the connection error at the joint
between patterns having different pitches decreases.
Accordingly, it is possible to minimize connection errors
occurring when patterns having different pitches are
20 connected in juxtaposition with each other as in the prior
art. In an optical fiber with a Bragg diffraction grating
fabricated by using such a phase mask, unwanted peaks
other than the desired peak of the spectrum are reduced.
In addition, ripples in the group delay characteristics
25 are reduced.

The production method according to the present
invention is useful for both a process in which patterns
are written with the reduced scale factor being varied,

and a process in which repeating pattern data of grating-shaped grooves and strips, which have different pitches, are written in juxtaposition with each other.

5 Brief Description of the Drawings

Fig. 1 is a diagram for describing the principle that the connection error at the joint between patterns is minimized by the present invention.

Fig. 2 is a diagram showing an electron beam writing 10 method used in the method of producing a phase mask, and also showing a section of the phase mask.

Fig. 3 is a diagram showing the way in which a pattern having a varying pitch is written by connecting together patterns having different pitches.

15 Fig. 4 is a sectional view showing steps of an embodiment of the phase mask producing method according to the present invention.

Fig. 5 is a diagram for describing optical fiber processing and a phase mask used therefor.

20 Fig. 6 is a diagram schematically showing the way in which a phase mask pattern is written with an electron beam by using an electron beam writing system.

Fig. 7 is a diagram showing the way in which a plurality of patterns having different pitches are written 25 by multiple writing operations carried out in opposite directions.

Fig. 8 is a diagram showing the way in which a plurality of patterns having different pitches are written

by multiple writing operations carried out in the same
direction.

Fig. 9 is a diagram showing the reflection
characteristics of an optical fiber with a Bragg

5   diffraction grating fabricated by a specific example of
the present invention.

Fig. 10 is a diagram showing the group delay
characteristics of a linear chirped fiber grating
fabricated by using a chirped phase mask made by

10   performing writing once.

Fig. 11 is a diagram showing the group delay
characteristics of a linear chirped fiber grating
fabricated by using a chirped phase mask made by
performing writing twice.

15   Fig. 12 is a diagram showing the group delay
characteristics of a linear chirped fiber grating
fabricated by using a chirped phase mask made by
performing writing four times.

Fig. 13 is a diagram showing the group delay ripple

20   in the case of Fig. 10.

Fig. 14 is a diagram showing the group delay ripple
in the case of Fig. 11.

Fig. 15 is a diagram showing the group delay ripple
in the case of Fig. 12.

25   Fig. 16 is a diagram showing the reflection
characteristics of an example of conventional optical
fibers with a Bragg diffraction grating.

Best Mode for Carrying Out the Invention

The method of producing an optical fiber-processing phase mask according to the present invention will be described below on the basis of embodiments thereof.

5   Fig. 2(b) shows a sectional view of a part in the longitudinal direction of a phase mask 21 for fabricating a Bragg diffraction grating in an optical fiber by a setup such as that shown in Fig. 5(a). The phase mask 21 has a repeating pattern of grooves 26 and strips 27 alternating

10   with each other. The grooves 26 and the strips 27 of the mask 21 are formed as shown in the top view in Fig. 2(a). The surface of a quartz substrate coated with an electron beam resist (see Fig. 4) is subjected to raster scan to carry out writing in such a manner that scanning lines 28

15   of the electron beam extend in a direction parallel to the grooves 26, thereby exposing the grooves 26. The strips 27 are made by blanking the electron beam scanning as shown by the broken lines in the figure. The exposure for the whole mask 21 of continuous length according to the

20   present invention is carried out by the following method. Raster scan is performed in the direction indicated by the double arrow in Fig. 2(a) (i.e. a direction perpendicular to the grooves 26 and the strips 27). As has been stated above, at a position where a groove 26 is to be written,

25   actual scan is performed with a predetermined number of scanning lines (5 scanning lines in the case of the illustrated example), and at the subsequent position where a strip 27 is to be written, scan is made blank for the

same number of scanning lines. This is repeated successively many times, whereby the phase mask 21 with a predetermined length is subjected to electron beam exposure at once.

5   More specifically, the method uses an electron beam writing system comprising, as shown schematically in Fig. 6, an electron gun 1, an electron lens 3 for converging an electron beam 2 emitted from the electron gun 1, an electron beam deflector 4 for deflecting the

10   converged electron beam 14, and a writing stage 5 movable in a direction (Y-direction) perpendicular to the scanning direction of the converged electron beam 14 scanned in one direction (X-direction) by the electron beam deflector 4. A phase mask blank 10 comprising a quartz substrate coated

15   with an electron beam resist is placed on the writing stage 5. While the writing stage 5 is being fed at a constant speed in a direction (Y-direction) perpendicular to the scanning direction, the grooves 26 are written on the phase mask blank 10 at predetermined repeating

20   intervals with the converged electron beam 14 deflected in the scanning direction (X-direction).

At this time, multiple exposure is carried out over the entire pattern area to minimize connection errors. The principle of this method will be described below. Fig. 3

25   is a diagram showing the way in which a pattern having a linearly or nonlinearly increasing or decreasing pitch is written by connecting together patterns P_1 to P_5 having different pitches. That is, the patterns P_1 to P_5 are

written successively and, while doing so, they are connected to one another. At this time, the boundary between each adjacent patterns, which forms a strip, may become narrower or wider than the desired set value owing to a connection error in the actual practice. Connection errors would form singular points on a fiber grating fabricated by using a phase mask having the connection errors, causing a large number of unwanted peaks other than the desired peak of the spectrum, as has been described in connection with Fig. 16. In a chirped grating, the connection errors result in ripples in the group delay characteristics. This may give rise to a serious problem when the chirped grating is used to compensate for dispersion of the optical fiber.

Fig. 1 is a diagram showing the boundary between the patterns P_1 and P_2. Reference numeral 26_1 denotes the final groove portion (solid line) of P_1 as written and exposed without an error. Reference numeral 26_2 denotes the first groove portion (solid line) of P_2 as written and exposed without an error. Reference numeral 26_3 denotes the final groove portion (broken line) of P_1 as multiple-exposed by the i-th writing process. Reference numeral 26_4 denotes the first groove portion (broken line) of P_2 as multiple-exposed by the i-th writing process. ΔXi represents the difference between the center position X of 26_1 and the center position Xi of 26_3. ΔYi represents the difference between the center position Y of 26_2 and the center position Yi of 26_4. It should be noted that Fig. 1 shows

the groove portions in consideration of a case where errors occur in both the grating repeating direction and the direction parallel to the grating grooves. When errors occur only in the grating repeating direction, there is no

5   error between the solid- and broken-line positions at each end in the direction parallel to the grating grooves.

If the portion exposed at the i-th time alone is considered, the connection error between P_1 and P_2 is given by $\Delta Y_i - \Delta X_i$. Incidentally, when multiple exposure is

10   carried out N times, the final pattern connection error is $(\Delta Y_1 + \cdots + \Delta Y_N)/N - (\Delta X_1 + \cdots + \Delta X_N)/N$. However, when i is 2 or more, the probability of the error $(\Delta Y_1 + \cdots + \Delta Y_N)/N - (\Delta X_1 + \cdots + \Delta X_N)/N$ becoming smaller than $\Delta Y_1 - \Delta X_1$ is high statistically. This means that the connection error

15   between P_1 and P_2 is made likely to decrease by multiple exposure. The same is the case with the connection between other patterns. After all, multiple exposure allows connection errors to decrease as a whole.

In this case, each pattern is written with a smaller

20   exposure dose than usual at all writing regions. Subsequently, each pattern is multiple-exposed at all the regions in such a manner as to overlap other patterns. When the number of times of writing each pattern in such a manner that the patterns overlap each other is one, the

25   exposure dose is a half of that in the conventional method. It is necessary that as the number of times of overlapping increases, the exposure dose should be reduced to a factor of the number of times of overlapping with respect to the

exposure dose used in the conventional method. It should be noted that writing may be performed by using an electron beam writing system. Alternatively, a laser beam writing system may be used.

5   As a specific example, a silica optical fiber improved in photosensitivity by loading it with high-pressure hydrogen was used as a photosensitive optical fiber 22 (Fig. 5), and refractive index modulation was produced directly in the core 22A of the photosensitive

10   optical fiber 22 by the setup shown in Fig. 5(a) using a phase mask 21 with a length of 35 mm and a uniform pitch continuously exposed by the above-described method of the present invention and produced through the following steps. It should be noted, however, that an argon SHG laser

15   (wavelength: 244 nm) was used as an ultraviolet radiation laser light source. The reflection characteristics of an optical fiber with a Bragg diffraction grating fabricated in this way are shown in Fig. 9 (in Fig. 9, the abscissa axis represents wavelength, and the ordinate axis

20   represents intensity). As will be clear from comparison to Fig. 16, undesired peaks are reduced.

The steps of producing the above-described phase mask 21 will be described below.

As basic pattern data, writing data for one pitch

25   consisting of 10 scanning lines, which comprises an address unit of 0.125 μm, is prepared. A reduced scale is given by (desired grating pitch)/(0.125×10). By using the reduced scale and the basic pattern data, an electron beam

resist applied to the surface of a transparent substrate is subjected to writing by an electron beam writing system. The following is a description of an example of the phase mask producing method according to the present invention, which uses the above-described writing method.

Fig. 4 is a sectional view showing the steps of this example. In Fig. 4, reference numerals denote as follows: 10 denotes a blank for a phase mask; 11 denotes a quartz substrate; 12 denotes a chromium thin film; 12A denotes a chromium thin film pattern; 12B denotes chromium thin film openings; 13 denotes an electron beam resist; 13A denotes a resist pattern; 13B denotes resist openings; 14 denotes electron beam; 21 denotes a phase mask; 26 denotes grooves; and 27 denotes strips.

First, as shown in Fig. 4(a), a blank 10 having a chromium thin film 12 grown to a thickness of 150 Å on a quartz substrate 11 by sputtering was prepared. The chromium thin film 12 is useful for preventing charge-up when the electron beam resist 13 is irradiated with an electron beam 14 at a subsequent step, and serves as a mask when grooves 26 are made in the quartz substrate. The control of the thickness of the chromium thin film 12 is important also from the viewpoint of resolution in etching of the chromium thin film. An appropriate chromium thin film thickness is 100 to 200 Å.

Next, as shown in Fig. 4(b), an electron beam resist 13 was applied to a thickness of 400 nm and dried.

Thereafter, as shown in Fig. 4(c), the electron beam

resist 13 was subjected to writing at an exposure dose of 0.6 µC/cm² by an electron beam writing system MEBESIII (manufactured by ETEC) to write a plurality of juxtaposed patterns each comprising grooves and strips of the same

5   pitch. Subsequently, the same patterns were written at 0.6 µC/cm² in such a manner as to be superimposed on the first-written patterns. At this time, the writing sequence is reversed, as shown in Fig. 7. It should be noted that the direction of the second writing may be the same as

10   that of the first writing, as shown in Fig. 8.

After exposure, baking (PEB: Post Exposure Baking) was carried out for 5 minutes at 90°C. Thereafter, the electron beam resist 13 was developed with TMAH (tetramethyl ammonium hydroxide) having a concentration of

15   2.38% to form a desired resist pattern 13A as shown in Fig. 4(d). It should be noted that the post exposure baking (PEB) is carried out to increase the sensitivity selectively at the portions irradiated with the electron beam 14.

20   Next, with the resist pattern 13A used as a mask, dry etching was performed by using CH₂Cl₂ gas to form a chromium thin film pattern 12A as shown in Fig. 4(e).

Next, as shown in Fig. 4(f), with the chromium thin film pattern 12A used as a mask, the quartz substrate 11

25   was etched to a depth of 240 nm by using CF₄ gas. The control of the depth is effected by controlling the etching time. It is possible to perform etching under control in the depth range of 200 to 400 nm.

Thereafter, as shown in Fig. 4(g), the resist
pattern 13A was removed with sulfuric acid at 70°C. Next,
as shown in Fig. 4(h), the chromium thin film pattern 12A
was removed by etching with a ceric nitrate ammonium

5   solution, followed by a cleaning treatment, thereby
completing a phase mask 21 having lines (strips 27) and
spaces (grooves 26) with a depth 240 nm and a pitch of
1.07 μm.

By using this phase mask, a diffraction grating was

10 formed in the core of an optical fiber. Wide-band light
with a 1.55 μm band was input into the optical fiber, and
the reflection spectrum of the diffraction grating was
measured. As a result, it was possible to obtain a
spectrum having reduced noise components as shown in

15 Fig. 9.

The foregoing is an example of improving the
reflection spectrum of a fiber grating with a uniform
pitch. The use of the present invention also makes it
possible to improve the group delay characteristics of a

20 chirped fiber grating in which the pitch changes linearly
or nonlinearly in the longitudinal direction. Figs. 10 to
12 show the respective group delay characteristics of
linear chirped fiber gratings fabricated by using three
different types of chirped phase masks different in the

25 number of times of writing. In these figures, the abscissa
axis represents wavelength, and the ordinate axis
represents relative group delay. The linear chirped fiber
gratings had a length of 100 mm, a bandwidth (full width

at half maximum) of about 1 nm and a reflectivity of 99%. It should be noted that the chirped phase masks used to fabricate the linear chirped fiber gratings were made through steps similar to those in the case of making the above-described phase mask having a uniform pitch by connecting together 100 patterns written in juxtaposition with each other so as to have different pitches changing linearly from 1.0722 μm to 1.0730 μm according to the following equation:

$$\Lambda(i) = (\Lambda_0 + \Delta\Lambda \times i)/n$$

($\Lambda(i)$ is the pitch of the i-th pattern, and n is the refractive index of the core of the optical fiber)

Fig. 10 shows the group delay characteristics of the linear chirped fiber grating obtained by the conventional making method, i.e. by using a mask produced by carrying out the writing process only once. Fig. 11 shows the groups delay characteristics of the linear chirped fiber grating fabricated by using a mask produced by carrying out the writing process twice. Fig. 12 shows the group delay characteristics of the linear chirped fiber grating fabricated by using a mask produced by carrying out the writing process four times. It is clear that as the number of times at which writing is carried out increases, the linear chirped fiber grating obtained by using the mask exhibits smoother group delay characteristics. Figs. 13 to 15 show the respective deviations from a straight line of the group delay characteristics in Figs. 10 to 12 obtained

by rectilinear congruence, which means the group delay ripple. In these figures, the abscissa axis represents wavelength, and the ordinate axis represents group delay ripple. In Fig. 13, the group delay ripple is of the order

5   of ±15 ps. In Fig. 14, the group delay ripple is of the order of ±10 ps. In Fig. 15, the group delay ripple is within ±10 ps.

Although the method of producing an optical fiber-processing phase mask according to the present invention,

10   together with an optical fiber with a Bragg diffraction grating fabricated by using the optical fiber-processing phase mask, have been described above on the basis of embodiments thereof, the present invention is not limited to the foregoing embodiments but can be modified in a

15   variety of ways. It should be noted that although in the foregoing invention a raster scan type system is used as an electron beam writing system, the present invention is also applicable to cases where a vector scan or other type of electron beam writing system is used.

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Industrial Applicability

As will be clear from the foregoing description, according to the present invention, multiple exposure is carried out to make a mask having a plurality of

25   juxtaposed patterns with a uniform groove-strip width ratio. Therefore, positional inaccuracies are averaged, so that the connection error at the joint between patterns having different pitches decreases. Consequently, in a

fiber grating having a uniform pitch, no unwanted peak occurs at either side of the central Bragg wavelength. Accordingly, wavelength selectivity is improved. In a chirped fiber grating in which the pitch changes linearly

5   or nonlinearly, ripples in the group delay characteristics are reduced. Thus, dispersion compensation characteristics are improved markedly.